LCA Case Studies

Rebound Effects of Price Differences*

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DOI: http://dx.doi.org/10.1065/lca2006.12.297

Please cite this paper as: Thiesen J, Christensen TS, Kristensen TG, Andersen RD, Brunoe B, Gregersen TK, Thrane M, Weidema BP (2008): Rebound Effects of Price Differences. Int J LCA 13 (2) 104–114

Abstract

Goal, Scope and Background. Traditionally, comparative life cycle assessments (LCA) have not considered rebound effects, for instance in case of significant price differences among the compared products. No justifications have been made for this delimitation in scope. This article shows that price differences and the consequent effects of marginal consumer expenditure may influence the conclusions of comparative LCA significantly. We also show that considerations about rebound effects of price differences can be included in LCAs.

Methods. The direct rebound effect of a price difference is marginal consumption. Based on statistical data on private consumption in different income groups (Statistics Denmark 2005a, 2005b), the present article provides an estimate of how an average Danish household will spend an additional 1 DKK for further consumer goods, when the household has gained money from choosing a cheaper product alternative. The approach is to use marginal income changes and the following changes in consumption patterns as an expression for marginal consumption. Secondly, the environmental impact potentials related to this marginal consumption are estimated by the use of environmental impact intensity data from an IO-LCA database (Weidema et al. 2005). Finally, it is discussed whether, and in which ways the conclusions of comparative LCAs can be affected by including the price difference between product alternatives. This is elucidated in a case study of a comparative LCA screening of two different kinds of Danish cheese products (Fricke et al. 2004).

Results. Car purchase and driving, use and maintenance of dwelling, clothing purchase and insurance constitutes the largest percentages of the marginal consumption. In a case study of two cheeses, the including the impact potentials related to the price difference results in significant changes in the total impact potentials. Considering the relatively small price difference of the two products, it is likely also to have a significant influence on the results of comparative LCAs more generally.

Discussion. The influence of marginal consumption in comparative LCAs is relevant to consider in situations with large differences in the price of the product alternatives being compared, and in situations with minor differences in the impact potentials related to the alternatives. However, different uncertainties are linked to determining the pattern for marginal consumption and the environmental impact potential related to this. These are first of all related to the method used, but also include inaccurate data of consumption in households, aggregation and weighting of income groups, aggregation of product groups, estimation and size of the price difference, and the general applicability of the results.

Conclusion. Incorporating marginal consumption in consequential LCAs is possible in practice. In the case study used, including the rebound effects of the price difference has a significant influence on the result of the comparative LCA, as the result for the impact categories acidification and nutrient enrichment changes in favour of the expensive product.

Recommendations and Perspectives. It is recommended that the rebound effects of price differences should be included more frequently in LCAs. In order to ensure this, further research in marginal consumption and investment patterns and IO data for different countries or regions is required. Furthermore, this study does not consider the economic distributional consequences of buying an expensive product instead of a cheaper product (e.g. related to how the profit is spent by those who provided the product). It should also be noted, that more expensive products not necessarily result in less consumption, as those who provided the product also will spend the money they have earned from the sale. Ideally, these consequences should also be further investigated. Likewise, the development of databases to include marginal consumption in PC-tools is needed. In general, considerations of marginal consumption would favour expensive product alternatives, depending, however, on the type of consumer.

Keywords: Consequential LCA; consumption dynamics; income elasticity of demand; I-O Analysis; marginal consumption; price differences; rebound effect; sustainable consumption; system delimitation

1 Rebound Effect and Marginal Consumption

The integration of economic aspects in LCA has recently gained momentum. This is reflected by the development and diffusion of tools such as IO LCA, total cost assessments, life cycle costing in LCA, and more refined methods for system delimitation, i.e. consequential system delimitation. The latter represents a market based approach to system delimitation as opposed to a delimitation based on physically interrelated flows (see Ekvall and Weidema 2004). Increased attention has also been given to the rebound effect which is related to system delimitation. The rebound effect[1] deals with the fact that improvements in efficiency often lead to cost reductions that provide the possibility to buy more of the improved product or other products or services (Binswanger 2001, Hertwich 2005). The energy consumption related to electronic appliances can illustrate this. The energy consump-

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[1] This definition refers to the 'direct' rebound effect. The 'indirect' rebound effect relates to the macro level impacts or effects on production rather than on individual consumer habits. For instance, improvements in energy efficiency may generally reduce the energy costs in the industry – leading to price reductions of goods and services and therefore increased demand for these products (Hertwich 2005).

tion tends to increase despite of efficiency improvements, as the number of appliances used in the households has grown even more (European Environment Agency 2005). Another example is the flat-screen technology which influences the consumers to buy larger TV-sets (or computer screens) – partly because they become cheaper and partly because they take up less space in the living room.

Even for the most promising energy saving technologies, such as energy saving light bulbs, there is also a downside. The total cost of ownership is considerably smaller compared to conventional light bulbs (in Denmark), leaving the consumer with an additional purchasing power. The money is most likely used for other products, which have environmental impacts that should also be accounted for. In a comparative LCA of e.g. conventional and energy saving light bulbs, it could be argued that the environmental impacts related to the additional consumption should be added to the impacts of the energy saving light bulbs in order to take the rebound effects into account. The environmental impacts of the additional consumption can be denoted as a rebound effect caused by the choice of the cheaper alternative. The modelling and importance of the rebound effects related to additional consumption is the focus of the present study.

However, taking a systematic approach, ideally the economic distributional consequences (e.g. related to how the profit is spent by those who provided the product) and following the environmental impacts related to this should also be included when comparing two alternatives. This consideration does not necessarily imply that more impacts should be attributed to the expensive product, as it is the profit ratio, meaning the size of the profit compared to the price of the product, which is of importance. The inclusion of the economic distributional consequences has not been part of the scope.

The simplest way to estimate how the money saved will be used is to assume that the money is spent on various products (or services) in the same proportion as the average expenditure. According to Hertwich (2005) a more refined method, applied in this article, is to estimate the *marginal consumption* of an average consumer or of consumers in a specific income group.

Weidema (2003) recommends including marginal consumption in comparative LCAs if there is a large price difference between the alternatives. Marginal consumption is also discussed by Goedkoop and others (1999) where the so called E2-vectors are introduced. An E2-vector describes the relation between environmental impacts and expenses, and the impact intensity of spending the money saved is used to calculate the overall impact of a product or service system. This article takes its point of departure in the hypothesis that it is practically possible and also important to include the price difference between two (or more) product alternatives in a comparative LCA.

2 Methodologies

Several methods can be considered for determining how an increase of 1 DKK[2] in the disposable income of an average Danish household will be spent among different product groups. The overall approach for this study is based on Andersen et al. (2005) who are estimating the structure of the marginal consumption from consumer expenditure surveys. The approach is to use marginal income changes and the following changes in consumption patterns as an expression for marginal consumption, which can be seen as short-term changes in consumption patterns[3].

The point of departure is that households in different income groups spend their disposable income differently among different product groups. Thus, when a household in an income group increases its disposable income by choosing a cheaper product, this study assumes that the consumption pattern of the household changes towards the consumption pattern of the adjacent higher income group. The difference between the consumption patterns of the two income groups is calculated and used as a representation of the distribution of the marginal consumption for the specific change to a higher income group. The motivation for the approach is that the money saved is seen as an addition to the household income, in the sense that the household get a specific need fulfilled, but by choosing the cheaper alternative the household also get more money for other consumption. Therefore, this household, in theory, can be perceived as richer than it would have been if the more expensive alternative had been chosen. The assumption is then that the money released not will be spend in accordance with the consumption pattern of the income group in which the household is found, but also will be affected by the consumption pattern of the adjacent higher income group. This assumption is made because the household, in theory, has moved toward the next income group by choosing the cheaper product and thereby having more money for other consumption.

2.1 Data collection

The data used have been obtained from 2705 households during the years 2001–2003 (Statistics Denmark 2005a, 2005b). Data are collected within a period of three years to even out fluctuations (Statistics Denmark 2005b:5). Households are divided into five different intervals according to their total annual income. For each income group, the data provide the total annual income, annual income taxes, annual net savings, annual disposable income and consumption, divided on 188 different product groups (Statistics Denmark 2005a). The distinction between the different product groups is very important due to the fact that different environmental impact potentials are related to each product group. Examples of product groups are cars, wine, expenses to dentist, and rentals for housing. The complete list can be seen in Statistics Denmark (2005a). Due to differences in data aggregation, however, some of the product groups used by Statistics Denmark (2005a) are not similar to the product groups of the IO database, which is presented in a subsequent section. Thus, it has been necessary to match the product groups with the most closely corresponding product groups in the IO model. **Table 1** illustrates how the product groups of the two sources have been matched.

[2] 100 € is approximately 750 DKK.

[3] Vringer (2005) is an example of a study which investigates long-term changes in consumption patterns caused by economic changes, technical and demographic changes and changes in consumer behaviour. The investigation was used to estimate which effect changed consumption patterns have on the energy requirement of Dutch consumers in 2030.

Table 1: The match of the product groups of the IO model (Weidema et al. 2005) with the product groups used by Statistics Denmark (2005a)

Product groups (IO model)	Product groups (Statistics Denmark 2005a)	Product groups (IO model)	Product groups (Statistics Denmark 2005a)
Bread and cereals	Rice; bread, dry cakes, cookies and biscuits; pasta products; cakes, ready-prepared dishes with bread; flour, cereals	Domestic services and home care services	Domestic services; household service
Meat	Beef and veal; pork; meat of lamb; poultry; offal, spreads, bacon, sausages; processed meat, meat products; other fresh meat	Medical and pharma-ceutical products	Medical products, vitamins, etc.; other medical products
Fish	Fresh and frozen fish; shellfish (not tinned); smoked and salted fish; processed fish, shellfish, fish products	Therapeutic equipment	Spectacles, etc.; hire of contact lenses and spectacles
Milk, cream, yoghurt etc.	Whole milk, semi-skimmed, skimmed, butter milk; breast-milk replacement, soya milk; junket, yoghurt; other dairy products	Medical doctors and dentists	General practitioner; physiotherapist, chiropractor, etc.; dentist
Cheese	Cheese	Hospital services	Hospitals
Fruit and vegetables, except potatoes	Citrus fruit; bananas; apples; pears; peaches, plums, avocado, other stone fruits; berries; other fruit; dried fruit, nuts; conserved fruit, fruit salad; leaf and stick vegetables; cabbage; tomatoes, cucumbers, peppers, peas; root vegetables, onions, mushroom; dried vegetables; processes and mixed vegetables	Dwelling, use and maintenance	Rentals for housing; permanent rentals for secondary dwellings, etc.; rental value of owner-occupied dwelling; rental value of free accommodation; rental value of own secondary dwelling; materials for repairs, etc. of dwellings; repairs, services of skilled craftsmen; miscellaneous maintenance
Butter, oils and fats	Butter; margarine in all forms; olive oil; other vegetable oils; lard, deep-frying fat	Transport services	Taxi-cabs; airline tickets; ferries; combined passenger transport; other transport services
Ice cream, chocolate and sugar products	Jams, honey; chocolate; sweets, marzipan; ice-cream; other sugar products	Tools & equipment for recreation	Equipment for sports, camping, etc.
Potatoes etc.	Potatoes; potato-based products	Radio and tv sets etc.	Radio, music players, etc.; TV-sets, video recorders
Sugar	Sugar, other sugar products	Photographic equipment etc.	Photographic equipment, video cameras; microscopes, binoculars, magnifying glasses
Eggs	Eggs	Recording media	Cd, video tapes and photos
Salt, spices, soups etc.	Sauces, condiments; salt, spices, vanilla; baking powder, yeast, soup, bouillon; preservatives	Data proc. equipm.	Personal computers, etc.
Coffee, tea and cocoa	Coffee, coffee products; tea, tea products; cocoa	Repair of a/v and data proc. equipm.	Repair of radio, TV-sets, pc, photo equipment, etc.
Mineral waters, soft drinks and juices	Mineral water; soft drinks; fruit juices; vegetable juices	Major durables f. recreation & culture n.e.c.	Caravans, boats, etc.; repair of caravans, boats, musical instruments, etc.; musical instruments, etc.
Wine and spirits	Spirits; wine; port, fortified wines, champagne etc.	Christmas trees	Plants, flowers, fertilizers, etc.
Beer	Beer	Catering, dom	Restaurants, etc.; canteens
Tobacco	Cigarettes; cigars, cheroots; tobacco, other tobacco products	Recreational items n.e.c.	Games, toys, hobby goods
Clothing purchase	Clothing materials; garments for men; garments for women; garments for children and infants; clothing, accessories	Petfood and veterinarian services	Pets, pet foods and accessories; veterinary and other services relating to pets
Laundering, dry cleaning etc.	Laundering, dry cleaning, repair of clothing	Communications	Postage; purchase of telephone and equipment; telephone services, call charges
Footwear	Footwear for men; footwear for women; footwear for children and infants; repair of footwear	Books, newspapers etc.	Books; newspapers, magazines
Car purchase and driving	Cars; motor cycles, etc.; bicycles; spare parts, accessories for vehicles; petrol, lubricants; repair, etc. of vehicles; other services relating to vehicles; vehicle license duty	Recreational and cultural services	Sporting activities, fairs, etc.; football pools, lottery, bingo, etc.; musicians, photographers, film developing, etc.; museums, zoological gardens, etc.; cinemas, theatres, concerts; TV license fees, rental of TV-equipment, films
Water supply	Water supply; water drainage, sewerage	Package holidays, dom	Package holidays
Refuse collection, other services n.e.c.	Refuse collection	Schools and other education, dom	Leisure-time education, youth schools, etc.; further and higher education; general schools, upper-secondary education, other education
Electricity (unconstrained), DK	Electricity	Stationery and drawing materials etc.	Printed matter; stationary and drawing materials

Table 1: The match of the product groups of the IO model (Weidema et al. 2005) with the product groups used by Statistics Denmark (2005a) (*cont'd*)

Product groups (IO model)	Product groups (Statistics Denmark 2005a)	Product groups (IO model)	Product groups (Statistics Denmark 2005a)
Gas	Town, natural gas; bottled gas	Accommodation services, dom	Hotels, campsites, etc.
Liquid fuels (reconstructed)	Liquid fuel	Hairdressing salons etc., dom	Hairdressers, beauty, etc.
Forestry products, DK	Solid fuel	Kindergartens, creches etc.	Day-care institutions, etc.
District heat, DK, (unconstrained)	District heating	Services, dom	Prostitution; other services
Furniture & furnishing	Furniture and furnishing; carpets, rugs; repair of furniture, household articles, etc.	Jewellery, clocks and watches	Jewelery, watches, etc.
Household textiles	Household textiles	Personal effects n.e.c.	Sunglasses, pipes, bags, prams, etc.
Major household appliances	Refrigerators, freezers; washing machines, tumble driers, dishwashers; cookers; extractor fans, elec./gas fan ovens, etc.; vacuum cleaners, etc.; electric sewing machines; household appliances over DKK 500; household appliances under DKK 500; repair of household appliances	Personal hygiene appliances and products	Toiletries, electric razors, etc.; soap, toothpaste, diapers, etc.
Glass, tableware and household utensils	Glasses, tableware, kitchen ware; kitchen and domestic utensils; cutlery, etc.	Insurance	Life insurance; family and household insurance; accident and health insurance; transport insurance; other insurances
Tools & equipment for house and garden	Major tolls and equipment; tools and equipment	Financial services n.e.c.	One-time fees and service charges for bank and insurance services
Non-durable household goods	Cleaning and polishing agents; other consumables		

The five different income groups used in this study are shown in **Table 2** together with the average disposable income for each income group, the number of households in each group, the purchasing power (the product of the average disposable income and the number of households) and the relative purchasing power for each income group. The use of the purchasing power is explained later. Throughout the article, the income groups will be referred to in text by the number given in Table 2.

2.2 Modelling the marginal consumption

Because of the five income groups, four changes from one income group to the adjacent higher income group can be modelled. **Table 3** shows an example of these calculations for the shift between income group 1 and 2 for the 15 product groups which constitute the largest part of the average consumption pattern in income group 1. The two first columns show the average consumer expenditure on different products of households in income group 1 or 2, whereas the third column shows the difference between average households in the income groups. The figure in the third column in the row 'In Total' shows the difference in disposable income between the income groups. The last column shows the difference for each product group as a percentage of the total difference in disposable income. These figures are used to calculate the distribution of the marginal consumption.

Four marginal consumption patterns are calculated in this way, one for each shift from one income group to the adjacent higher income group. This can be described as a 188 by 4 matrix, the rows represent product groups, and the columns represent the shifts between income groups. The entries in the matrix represent the percentage of the total difference in disposable income that is spent on the product group in question. Part of

Table 2: Income intervals, average disposable income and total number of Danish households within each of the five different income groups (Statistics Denmark 2005a). The purchasing power is the average income in each group multiplied with the total number of households. The relative purchasing power shows how large a share each income group has in the total purchasing power of all consumers

Income groups	Average disposable income per household (DKK)	Total number of households in thousands	Purchasing power in thousands (DKK)	Relative purchasing power
1: Less than 150,000 DKK	114,060	367.3	41,893,650	6.97%
2: 150,000–299,999 DKK	163,961	709.8	116,378,808	19.37%
3: 300,000–499,999 DKK	225,971	558.2	126,136,845	21.00%
4: 500,000–799,999 DKK	316,256	582.3	184,155,811	30.66%
5: 800,000 DKK or more	432,597	305.5	132,158,261	22.00%

Table 3: Differences in consumption between income group 1 and 2 for the 15 product groups which constitute the largest parts of the consumption for income group 1

Product groups	Income group 1 (DKK)	Income group 2 (DKK)	Difference between income group 1 and 2 (DKK)	Difference as percentage of change in disposable income
Dwelling, use and maintenance	29,871	40,220	10,349	20.7%
District heat, DK	6,928	7,830	902	1.8%
Clothing purchase	4,089	5,473	1,384	2.8%
Catering, domestic	3,979	5,252	1,273	2.6%
Car purchase and driving	3,786	13,138	9,352	18.7%
Electricity, DK	3,728	4,558	830	1.7%
Communications	3,654	4,601	947	1.9%
Recreational and cultural services	3,564	5,343	1,778	3.6%
Transport services	3,392	3,056	-337	-0.7%
Meat	3,214	4,458	1,244	2.5%
Tobacco	2,615	3,578	963	1.9%
Books, newspapers etc.	2,489	2,275	-214	-0.4%
Bread and cereals	2,440	3,196	756	1.5%
Fruit and vegetables, except potatoes	2,421	2,963	542	1.1%
Insurance	2,393	5,243	2,851	5.7%
Residual	35,497	52,779	17,281	34.6%
In total	114,060	163,961	49,901	100.0%

this matrix is presented as the four middle columns of **Table 4.** Table 4 shows the distribution of marginal consumption over different product groups (a vector with 188 entries). Only the fifteen product groups that constitute the largest parts of the marginal consumption and the five product groups which constitute the smallest parts are shown.

Table 4: Distribution of 1 DKK for the four different shifts to an adjacent higher income group, based on (Statistics Denmark 2005a). The weighted average is shown in the right column. The percentages show how the difference in consumer expenditure is used on different product groups. As an example, income group 2 have 49,901 DKK more for consumption than income group 1 (see Table 3, the row 'In Total'). Of this difference, 18.7% will be spent on car purchase and driving

Product groups	Distribution of 1 additional DKK Group 1 to 2	Distribution of 1 additional DKK Group 2 to 3	Distribution of 1 additional DKK Group 3 to 4	Distribution of 1 additional DKK Group 4 to 5	Weighted average distribution of 1 additional DKK
Car purchase and driving	18.7%	20.9%	21.7%	22.6%	18.6%
Dwelling, use and maintenance	20.7%	8.0%	11.7%	15.2%	16.5%
Clothing purchase	2.8%	4.6%	3.5%	7.9%	5.2%
Insurance	5.7%	5.4%	3.8%	3.3%	4.2%
Catering, domestic	2.6%	4.0%	3.4%	4.2%	3.7%
Furniture and furnishing	1.4%	3.7%	2.2%	3.1%	2.7%
Recreational and cultural services	3.6%	3.5%	1.1%	2.7%	2.6%
Consumption by private non-profit institutions, domestic	2.4%	4.3%	3.6%	0.7%	2.5%
Meat	2.5%	2.4%	2.6%	2.4%	2.5%
Package holidays, domestic	1.5%	2.0%	2.4%	2.2%	2.1%
Fruit and vegetables, except potatoes	1.1%	2.1%	1.4%	2.2%	1.8%
Kindergartens, crèches, etc.	0.1%	2.8%	4.1%	0.2%	1.7%
Wine and spirits	1.5%	0.4%	1.6%	2.6%	1.7%
Bread and cereals	1.5%	2.2%	2.1%	1.2%	1.7%
Electricity, DK	1.7%	1.2%	2.3%	1.4%	1.7%
Christmas trees	0.1%	0.1%	0.1%	0.1%	0.1%
Hospital services, domestic	0.1%	0.2%	-0.13%	0.1%	0.1%
Laundering, dry clean	-0.1%	0.3%	-0.2%	0.2%	0.04%
Sugar	0.03%	0.01%	0.00%	0.02%	0.01%
Repair of a/v and data proc. equipment	-0.3%	0.05%	0.1%	-0.03%	-0.03%
Residuals	32.5%	32.3%	32.8%	28.1%	30.7%
Total	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

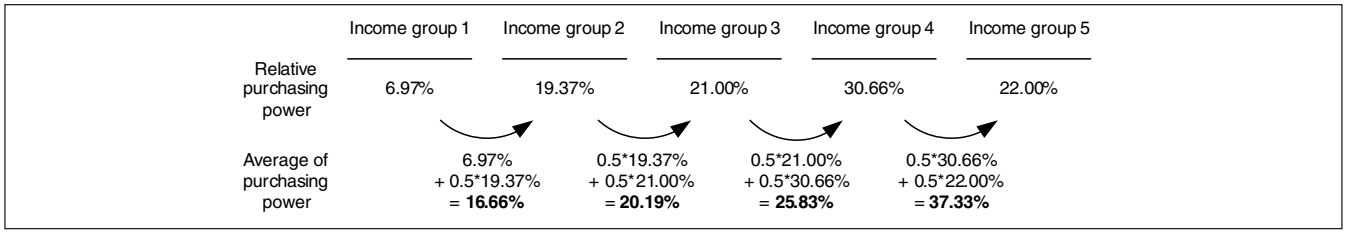

Fig. 1: Calculations of the weighting factors

The right column of Table 4 shows the average marginal consumption pattern, which can be obtained as a weighted average of the four marginal consumption patterns shown in the four other columns. The figures are weighted to let the size of consumption have an influence: the more money the household has available for consumption, the more often the household will have the possibility to choose between different alternatives and thereby release money for other consumption. Secondly, the number of households in each income group differs, and the income groups representing the most households should be given more influence. The weighting is therefore conducted according to the relative purchasing power of the households that are assumed to exhibit the respective marginal consumption patterns. The assumptions regarding how the rest of the purchasing power will be spent if released by choosing a cheaper product alternative are presented in **Fig. 1**.

The figure can be explained with an example: as seen in Fig. 1 the relative purchasing power of income group 1 is 6.97%, whereas the relative purchasing power of income group 2 is 19.37%. We are then assuming a simple linear relation to determine how differences in spending between income groups 1 and 2 should be weighted, and thus calculate the weighting factor as 6.97%+0.5*19.37%=16.66%.

The percentage differences in spending between income groups 1 and 2 (part of which is shown in the second column of Table 4) should thus be multiplied with this weighting factor, and this will show how much the differences between income groups 1 and 2 should influence the average distribution of 1 additional DKK. The same procedure is applied for the other three marginal consumption patterns, before the four of them are added together (presented in the right column of Table 4). The whole procedure amounts to multiplying the 188 by 4 matrix mentioned earlier with a vector consisting of the four values calculated in Fig. 1. This results in a vector with 188 entries describing the distribution of the average marginal consumption, adjusted according to purchasing power.

2.3 Estimating the environmental impact potential by IO LCA

To model the total impact potential of choosing between product alternatives with different prices, the next step is to estimate for each product group included in the marginal consumption patterns, the environmental impact intensity, i.e. the potential environmental impacts per 1 DKK of each product group. The data are provided by Weidema et al. (2005), who also supply an upgrade of the original EDIP method, which is also used for the LCIA in this study. A further explanation of the impact categories and normalisation references can be found in Weidema et al. (2005) and Wenzel et al. (1997).

In Weidema et al. (2005), data are based on an IO model of Danish production and final use, as well as foreign production of products used as input for Danish production or final use in year 1999. The IO model is derived from records of the National Account and balance of payment from Statistics Denmark (2003).

The environmental impact intensities can be described as vectors with one entry per impact category, in this case 11 entries. These vectors can be combined to an 11 by 188 matrix. Multiplying all the entries in this matrix by 1 is equivalent to a situation where 188 DKK are spent, 1 DKK on each product group.

Finally, for each product group, the marginal consumption per DKK is multiplied by the impact intensity. Aggregating similar impact categories over all product groups, we obtain the environmental impact potential of the marginal consumption pattern.

2.4 Inclusion of the marginal consumption in a comparative LCA

The resulting environmental impact potential of the marginal consumption has been applied to a comparative LCA of consumption of 250 g of two Danish yellow cheeses in different kinds of packaging. This LCA is based on a screening LCA conducted by Fricke et al. (2004). The system delimitation of the LCA is based on a consequential approach.

The two cheeses fulfil the same function regarding taste and quantity. One cheese is a 'convenience product' which comes in a packaging that is easy to open and close. The other cheese comes in a traditional and less convenient packaging which is assumed to entail the use of alternative, and thus extra, packaging in the household. The convenience product is also cut out at the dairy, which means that the cutting waste (44 g out of 294 g) is recycled at the dairy, whereas with the traditional packaging the cutting takes place in the household and the cutting waste ends up as household waste (Fricke et al. 2004).

Studies of retail prices during spring 2005 show that in order to consume 250 g of cheese, a consumer must pay 1.61 DKK more (incl. VAT) if choosing the convenience product over the less convenient product (Andersen et al. 2005). The price difference amounts to 8.6% of the price for the expen-

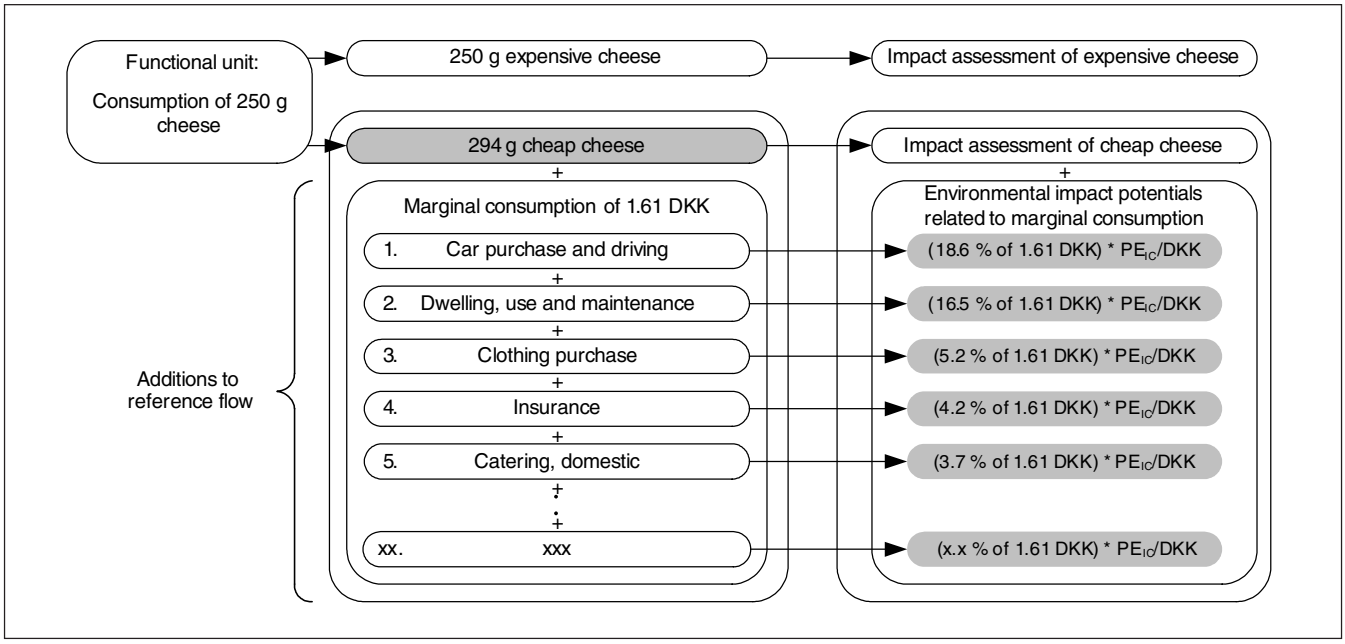

Fig. 2: The two cheeses fulfilling the same functional unit. The modification of the reference flow and environmental impact potential of the cheaper cheese alternative is added to show the rebound effect of the marginal consumption

sive cheese. We include the environmental impact potential related to the marginal consumption by multiplying the 1.61 DKK with the environmental impact potential of different impact categories for the marginal consumption of 1 DKK. This is then added to the environmental impact potential of the traditional and cheaper cheese to describe the total environmental impact potential related to choosing the cheaper traditional product instead of the more expensive convenience product (**Fig. 2**).

3 Results

The distribution of the marginal consumption over different product groups was partly presented in Table 4, and the distribution can be regarded as a first result of the studies. A second result is the environmental impact potentials related to the marginal consumption (a vector with 11 entries) which are shown in the first column of **Table 5** normalised to person-equivalents (PE). In order to show the difference between the marginal consumption and the average Danish consumption, Table 5 also includes the environmental impact potentials related to the average consumption of 1 DKK. The difference in percent, calculated with a point of departure in the average household consumption, is shown in the last column. As seen from Table 5, the environmental impact potentials related to the marginal consumption is quite similar to the environmental impact potentials related to the average consumption. For this particular case (i.e. Danish consumption), this implies that the environmental impact potentials of the average consumption could as well be used to represent the environmental impact potentials of the marginal consumption. The average consumption could at least be used to get an overview of whether or not the inclusion of marginal consumption could be of importance in a specific case, which could be followed by more precise modelling of the marginal consumption, if important.

Table 5: Directional normalised results (person-equivalents) for the environmental impact potentials related to consumption of 1 additional DKK. The normalisation reference used in this study is an upgrade of the EDIP LCIA method to 1999 i.e. the environmental impact potential connected to Danish consumption and final use in 1999. The figures are compared to the average Danish consumption

Impact categories	Marginal consumption, DK, 1DKK99 (PE)	Average Danish household consumption, 1 DKK99 (PE)	Difference (as % of average Danish household consumption)
Global warming	7.15E-06	6.95E-06	–2.88%
Ozone depletion	9.96E-06	9.24E-06	–7.79%
Acidification	2.79E-06	2.70E-06	–3.33%
Nutrient enrichment	3.56E-06	3.81E-06	6.56%
Photochemical ozone formation	2.56E-06	2.25E-06	–13.78%
Ecotox water chronic	2.06E-07	2.49E-07	17.27%
Ecotox water acute	3.55E-07	4.46E-07	20.40%
Ecotox soil chronic	1.43E-06	1.55E-06	7.74%
Hum tox air	6.74E-07	6.17E-07	–9.24%
Hum tox water	2.25E-05	2.03E-05	–10.84%
Hum tox soil	2.22E-05	2.00E-05	–11.00%

The normalised results of the comparative LCA, when adding the environmental impact potential of the marginal consumption to the impact potential of the cheaper cheese, is shown in **Fig 3.**

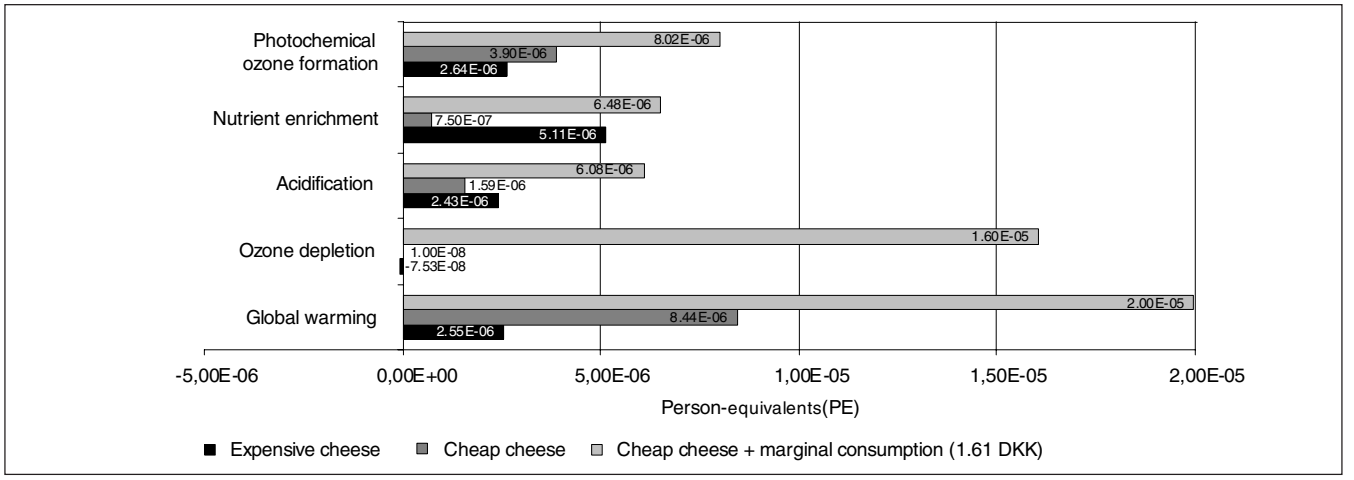

Fig. 3: The result of the comparative LCA when the environmental impact potentials related to marginal consumption are added to the cheaper alternative

Fig. 3 shows that the more expensive product alternative has higher environmental impact potentials for the impact categories acidification and nutrient enrichment[4]. When including the environmental impact potentials related to marginal consumption in the reference flow of the cheap cheese, the normalised results changes for both impact categories resulting in the more expensive product alternative having a lower environmental impact potential for all categories than the cheaper alternative.

As seen from the figure, the rebound effect of a price difference has a visible effect on the environmental impact potential of the cheaper product alternative. These results show that the inclusion of the environmental impact potentials related to marginal consumption has the potential of changing the results for some impact categories of a comparative LCA. This can be the case even when the price difference is very small, as is the case in the comparative LCA of Danish cheese. Here it is seen that including the environmental impact potentials related to the consumption of an additional 1.61 DKK changes the conclusion for two different impact categories (four if the toxicities are included).

4 Discussion

To make the results of a comparative LCA transparent, it must be recommended to present the results separately with and without the impacts related to marginal consumption. This is also connected to the uncertainties related to the methods and results presented, which are described in section 4.1. Ideally, data on the marginal consumption should be available in PC-tools[5], to make it relatively simple to include the rebound effects. Our data are calculated from a Danish context, and might not be representative outside this context, as marginal consumption patterns are likely to differ around the world. These considerations are particularly relevant in situations where a product is sold in different parts of the world.

4.1 Uncertainties

Method used to estimate marginal consumption. For this study, consumer expenditure surveys have been the main data source. Another approach would be to evaluate the different consumption patterns of households who buy the cheap cheese and households who buy the more expensive product. However, this approach might be more feasible when the alternatives compared amounts to a larger share of the household budgets, Hertwich (2005) e.g. proposes to use this method to evaluate the marginal consumption of people who own cars compared to people who engage in car sharing programmes. Another option is to investigate how households actually spend money added to their budget – some might be choosing the cheaper alternative all year because they are saving up money for e.g. holiday-trips, while others let the money become part of the regular daily household budget. Through investigations of this kind, a more precise picture of consumer behaviour and marginal consumption patterns would be given. Ideally the economic distributional consequences of choosing one alternative over another should also be considered. As mentioned, this does not necessarily introduce a bias in relation to the expensive alternatives, as it is the profit ratio, not the size of the profit itself, which is of importance. When comparing two alternatives, ideally, the profit ratio should also be determined, and it should be assessed how an additional income would be spent by those who provided the product. This would give a more precise picture of the impacts related to the marginal consumption.

Environmental impact intensities. The data on environmental impact intensities originates from Weidema and others (2005). For each product and impact group a quantitative uncertainty assessment has been performed, and the rankings are provided with confidence intervals. Generally, the dif-

[4] The more expensive product alternative also has higher environmental impact potentials for the impact categories eco toxicity soil chronic, human toxicity air and human toxicity soil than the cheaper alternative. The normalised results for the toxicities also change for all categories (except human toxicity air) when the environmental impact potentials related to marginal consumption are added. However, as the results for the toxicities in general are somewhat uncertain, these are neither graphically represented nor commented further upon.

[5] The csv data-file for marginal consumption used in this study is available from http://www.plan.aau.dk/~06em0905/

ference between the product groups are so large that their overall position in the prioritisation is very stable, even for product groups where the environmental impact is determined with relatively large uncertainty. However, there are still some uncertainties related to the exact size of the environmental impact intensities, and the results presented in Table 5 and Fig. 3 are therefore only directional estimates of the influence of rebound effects.

Other studies have investigated environmental impacts related to different products. One example is the EIPRO study of the European Commission (Tukker et al. 2006), which identifies the products in the EU-25 having the greatest environmental impacts from a life cycle perspective. This study reaches the cautious conclusions that certain product groups (cars, food, heating and house building) are found to be in the top rankings of all the studies that have been reviewed in the EIPRO study. However, there is no coincidence between the specific figures attributed to the different product groups, and there is no conformity on the mid-range of product groupings[6].

Aggregation of income groups. Data are divided into five income groups depending on household income, which are given equal importance in the calculations. As the intervals are very large, there might be a large difference between the consumption pattern of a household in the lower end of an income interval compared to the consumption pattern of a household in the upper end of the same income interval. Furthermore, the different income groups can be assumed to contain different types of households, and therefore it might be imprecise to compare the consumption patterns of very different types of households. As an example, for the income groups 1–3, the average number of children is between 0 and 0.5, whereas there are between 0.8 and 0.9 children in an average household in income group 4–5. Another example is the number of adults in a household, which also increases as the household income increases. With a larger number of income groups, it would be possible to estimate more precisely how an additional DKK was spent in different groups and in average. In this study though, it has only been possible to obtain data for consumption patterns for five different income groups for Danish households. This aggregation level obviously introduces a cause of error, but is used in the lack of better statistical data. Future studies could include more income groups to study whether this has a significant impact on the results.

Weighting of income groups. In this study, the income groups have been weighted according to their purchasing power. However, other types of weighting could have been used; one option is to weight the income groups according to their expenditures for the specific product investigated, e.g. for our case study the expenditure for cheese, so that the income groups who use more money on cheese are given more importance. The distribution of the marginal consumption weighted according to expenditures for cheese and purchasing power is presented in **Table 6**, together with the difference in percent.

As seen from Table 6, this method for weighting only slightly changes the distribution of marginal consumption. However, for some product groups not shown in the Table, the differences are large.

Aggregation of product groups. In the present study, we have operated with 188 product groups in the data of Statistics Denmark, and 71 product groups in the IO model. Each of these groups obviously reflects great differences in specific product types and environmental impact potentials. One example is the product group fish of the IO model. Thrane (2006) shows that the environmental impact potential varies considerably as a function of the species type, but in our data many different types of fish products are aggregated in one group. This is a source of uncertainty, because it is assumed that the marginal consumption affects the average product within each product group, which is obviously not the case in all situations.

Estimation and size of price differences. The price difference between the alternatives has been estimated from numerous advertising flyers and visits to different supermar-

[6] Some explanations are; the studies use different impacts categories, only Weidema and others (2005) use a consequential approach to system delimitation, and the studies cover different regions (Tukker et al. 2006).

Table 6: The distribution of the marginal consumption, when weighting the income groups according to expenses for cheese

Product groups	Marginal consumption, 1DKK Purchasing power	Marginal consumption, 1DKK Cheese expenses	Difference (%)
Car purchase and driving	18.6%	18.2%	2.5%
Dwelling, use and maintenance	16.5%	17.5%	–6.1%
Clothing purchase	5.2%	5.5%	–5.1%
Insurance	4.2%	4.2%	2.0%
Catering, domestic	3.7%	3.7%	–0.8%
Furniture and furnishing	2.7%	2.7%	–0.1%
Recreational and cultural services	2.6%	2.6%	–1.3%
Consumption by private non-profit institutions, domestic	2.5%	2.2%	10.0%
Meat	2.5%	2.5%	0.1%
Package holidays, domestic	2.1%	2.1%	0.3%

kets and discount stores (Andersen et al. 2005). This reveals large uncertainties, as the price of the product alternatives vary from week to week, but also is depending on for instance the type of supermarket and its localization.

Considering price differences, it is also possible that the size of the prize difference has an influence on the character of the marginal consumption. As an example, a person who experiences a large price difference, for instance when buying luxury goods on sale, might celebrate it by buying other luxurious product for the money saved. On the other hand, saving 1.61 DKK when buying cheese would become part of the grocery shopping budget. Another example is the consumer, who saves up money throughout the year, in order to buy a summer vacation. These considerations show that many different aspects could have an influence on the rebound effect.

Applicability of results. As the data used is based on households, no considerations of e.g. different sex, occupations or age are taken. Therefore, it can be difficult to apply the marginal consumption pattern for different income groups to individuals. Furthermore, the data are based on qualitative information of alleged consumption.

When comparing some types of products, for instance luxury products that are sold to specific consumer segments with specific characteristics, it might be relevant to consider the marginal consumption of these consumer segments. One example is that when comparing two very expensive products, including the marginal consumption for the average household might give a false picture of the environmental impact potentials. Another example is that consumer segments with a high income are more likely to for instance buy expensive furniture designed by famous architects, which may represent a smaller impact potential per DKK compared to cheaper furniture. Therefore, the marginal consumption pattern and the impact potentials related to this might vary significantly from the marginal consumption pattern of less well-of households.

Other methodological considerations. The present study analyses the marginal consumption as a function of income groups, but it is possible that a part of the differences that is ascribed to differences in income groups are caused by other things than the income level in itself. Low income groups are typically single households, while middle income groups are dominated by families with small children. Obviously, having children in the household will affect the consumption pattern. Hence, ideally our study should be supplemented with an analysis of the changes in a specific person's consumption pattern over time.

Apart from the importance of the household configuration, we should ideally also consider the consumer segments. A more conscious or 'green' consumer would maybe feel more inclined to use savings for greener products, organic food, or membership fees to NGOs that support poverty alleviation, AIDS relief medicine, or rainforest conservation. Hence, it must be recognized that the quantitative approach applied in the current study ideally should be supplemented with qualitative studies that could unveil the importance of other relevant factors than income.

5 Conclusions

Inclusion of the environmental impacts related to price differences is an option when conducting comparative LCAs. This can be done by using statistics on private consumption and by modelling the marginal consumption pattern. These data can be combined with IO data on environmental impact potentials related to different product groups and thereby provide an estimate of the impact potentials related to price differences. In the example, where the suggested method is applied on a comparative LCA of two Danish cheese products, it becomes clear that the rebound effect actually has a significant effect on the results. The case shows that the results for the impact categories acidification and nutrient enrichment changes in favour of the more expensive product. The study hereby indicates that including rebound effects of price differences in comparative LCAs can give different results. As mentioned also the economic distributional consequences of choosing one alternative over another and the environmental impacts related to this should also be included, but this does not necessarily worsen the environmental performance of the expensive product, as it will depend on the profit ratio. In this regard it should also be noted, that more expensive products not necessarily result in less consumption, as those who provided the product also will spend the money they have earned from the sale, but again it is the size of the profit ratio which is of importance.

Combining data for private consumption with IO data could additionally be used in other situations, as it provides an overview of the impacts related to increased consumption in society. It is hereby possible to assess e.g. the environmental impact that will occur as a result of a tax relief or through other changes in the economy of consumers.

6 Recommendations and Perspectives

When using the combined data in an LCA it can result in a more correct assessment of the environmental impacts related to a choice between two alternatives, but it also depends on the questions that the study initially is supposed to answer. Generally, we would therefore recommend that results are shown both with and without the inclusion of marginal consumption – together with a further discussion of the question that the study seeks to elucidate. Applying marginal spending more generally requires further research in marginal consumption and investment patterns[7]. Also, other and more precise methods for determining the marginal consumption should be investigated, as well as IO data for different countries or geographical regions in the world are needed. Ideally such data should be available in currently available PC software.

It is both relevant and feasible, but not unproblematic, to include rebound effects of price differences in LCAs. In terms

[7] The investment patterns would give a better picture of how a profit is spent, and thereby give a more precise picture of the economic distributional consequences.

of consumer recommendations, inclusion of marginal consumption would generally favour the choice of expensive product alternatives, as this would bind the consumers' money in products, and thereby limit the consumption of further goods and services. This conclusion can also be supported by work of Peters and Hertwich (2004), which have shown that the CO_2 emission per NOK spent is more or less the same for all income groups, but that the emissions increase as the household income increase. Therefore, the more money a household can bind in expensive options, the less money is available for other consumption (in theory, by choosing a more expensive alternative the household can be perceived as becoming a little poorer). This conclusion presupposes that the single consumer acts like the average consumer, or the given consumer type that is being modelled. If the consumer donates the saved money to e.g. WWF, or to preserve the world's rain forests, the picture may change radically. In other words, it is inherent to the method that assumptions are made about consumer behaviour which are not necessarily true in a specific single case. In fact, it is possible that 'green' consumers, who are susceptible to green consumer advice, generally have a different behaviour than the average consumer, and therefore are more likely to use savings for green donations etc. Hence, it is possible that some bias exists in this type of modelling. Also, a general consumer recommendation that favours expensive products could be problematic because some consumer segments do not have, or do not feel they have, the choice to choose expensive products, especially when developing countries are considered. A way to handle this would be to adjust the consumer recommendations to different income groups and different countries.

In general, the question of rebound effects shows the importance of considering how money is spent, as there are environmental (as well as social and economic) impacts related to all consumption. As shown, the environmental impacts related to marginal consumption are to a large extent similar to the environmental impacts of the average consumption. This implies that the average environmental impacts (often available as the normalisation values in different impact assessment methods) can be used as a first proxy to include marginal consumption – thus making it feasible as a standard practice.

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Received: August 18th, 2006
Accepted: December 11th, 2006
OnlineFirst: December 12th, 2006